

The sustainability of communicative packaging concepts in the food supply chain. A case study: part 2. Life cycle costing and sustainability assessment

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Abstract

Purpose This paper is the second part of a two-paper series dealing with the sustainability evaluation of a new communicative packaging concept. The communicative packaging concept includes a device that allows changing the expiry date of the product as function of temperature during transport and storage: a flexible best-before-date (FBBD). Such device was analysed in a consumer unit consisting of a nanoclay-based polylactic acid tray filled with pork chops.

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Methods An economic assessment was made through the use of life cycle costing (LCC) methodology proposed by Bovea and Vidal (Resources, Conservation and Recycling Volume 41, Issue 2, May 2004, Pages 133–145) where both internal and external costs were considered. Furthermore, the social aspects were analysed using a contingent valuation (CV) of the willingness to pay (WTP). The sustainability assessment of FBBD was made through the combination of life cycle assessment (LCA) and LCC results, together with the CV of the WTP according to the method proposed by Bovea and Vidal. It was assumed that the use of the FBBD minimizes the food losses from 3.5% to 0.5%.

Results and discussion LCC results show that internal costs related to pork chops and logistic supply chain life cycle represent more than 90% of life cycle cost. The use of FBBD communicative device could increase pork chop selling price between 0.01 and 0.1€ since the purchasing cost of this communicative device is included in this price. WTP results show that FBBD purchasing cost for consumer acceptance is estimated as 0.05€/FBBD. Therefore, only pork chop selling price for scenarios 1 (0.05€/device) and 3 (0.01€/device) could be accepted by consumers. The most sustainable situation is reached when the cost of the FBBD is as less as possible (0.01€).

Conclusions The use of FBBD communicative device has economic advantages for perishable products since it contributes to the increase in the economic savings due to the reduction of food losses. However, these economic savings represent a small percentage over pork chop selling price, and therefore, an FBBD price less than 0.02€/device is required. If a lower price for the communicative device is reached, satisfying the WTP of consumers (0.05€/FBBD), the communicative package will be much more sustainable.

Recommendations It is expected that the competitiveness of FBBD communicative device will be improved in the future. This might be accomplished by reducing FBBD production and distribution costs and increasing their social acceptance, providing more sustainable solutions.

Keywords Contingent valuation · Life cycle costing · Packaging · Sustainability

1 Introduction

The deep integration of packaging in consumers' everyday life, and its influence on ecology and economy, makes packaging an important part in the overall drive for sustainable growth. As a result of that, a wide range of strategies have been used to minimize their environmental impacts: design improvements, the use of new materials, use of active packaging systems, or communicative devices to reduce the amount of product losses and to improve product traceability, etc. The development of these new packaging systems would enable opening new markets, increasing the number of materials, applications and products, as well as the number of manufacturers, converters and end-users, contributing to economic and social development.

One of the aims of SustainPack project was the development and assessment of new communicative packaging concepts. In that sense, several communicative devices were developed in this project, although one of them showed an interest for both consumers and retailers: the flexible-best-before-date (FBBD) communicative device in food packaging. Such device allows minimizing the amount of food losses of perishable products at retailer outlets since it facilitates a dynamic control of out-of-date products.

Methodologies such as Life Cycle Assessment (LCA) could be applied in order to assess the environmental behaviour of this new communicative packaging device. However, sustainability does not mean to consider only the environmental issues but also economic and social issues in order to assess their implications for the companies, customers and society (Kloepffer 2008). This well known and accepted approach of the triple bottom line was applied to the research activities within SustainPack project in order to assess the sustainability of the FBBD communicative device.

Consequently, economic and social analyses of the FBBD were required to carry out the sustainability analysis of this communicative packaging device. For the economic assessment, methodologies such as Life Cycle Costing (LCC) can be applied. Furthermore, social issues can be evaluated through the customer's valuation. This type of analysis provides data related to the willingness of future customers to pay the FBBD devices in packaging, both consumers and retailers. The customer valuation can be

carried out by applying contingent valuation techniques (CV), a survey-based method to quantify the customer's value in terms of his/her willingness to pay (WTP) for a product that incorporates certain environmental improvements, like the FBBD devices, since these could minimize the amount of food losses. However, the assessment cannot be done only to FBBD. Therefore, the whole consumer unit where the FBBD can be stuck was also considered. This consumer unit consists of a nanoclay-based polylactic acid (PLA) tray sealed with SiO_x-coated PLA film including the pork chops (Dobon et al. 2011).

For the economic assessment, there are many Life Cycle Costing methodologies that includes both internal and external costs incurred throughout the entire life cycle of a product, like the LCC methodology proposed by Bovea and Vidal (2004; Fig. 1). In Bovea and Vidal's LCC methodology (Bovea and Vidal 2004), internal costs (IC), also called company costs, are the costs for which the company is responsible over a particular period of time that includes conventional costs (CC), hidden costs (HC) and less tangible costs (LTC). CC include direct cost of manufacturing. HC are those related to licence expenses, waste management costs, etc. LTC are those which are often not included in the company accounts due to their probabilistic nature (e.g. marketing costs, etc.). Besides the internal costs and their subtypes, external costs (EC) are the costs for which the company is not responsible at a specific time. These kinds of costs are related to depletion of natural resources, impact on human health, etc. Most often, these costs are called social costs since in long term, they fall back on society as a whole and should be included in the company accounting. Once environmental, economic and social issues have been assessed, a sustainability measurement of the product can be carried out.

A comprehensive research and analysis of practical/quantitative alternative methods for sustainability assessment was carried out. Most of the reviewed sustainability methods were based on qualitative perceptions (Maxwell and van der Vorst 2003; Tukker 2004), and others did not consider environmental impacts (Isaksson 2005) or were rather difficult to be applied to the communicative packaging aim of this research (Schmidt 2006). As a result of this analysis, it was decided to apply the methodology proposed by Bovea and Vidal (2004). This methodology integrates environmental, cost and customer valuation by the combination of three methodologies: Life Cycle Assessment to evaluate the environmental requirements, Life Cycle Costing to examine the internal and external costs of the product and Contingent Valuation to quantify the consumer's value of terms of their Willingness To Pay for a product that incorporates certain environmental improvements. Moreover, it identifies the most sustainable alternatives according to the scope and objectives defined.

Fig. 1 LCC methodology proposed by Bovea and Vidal (Adapted from Bovea and Vidal 2004)

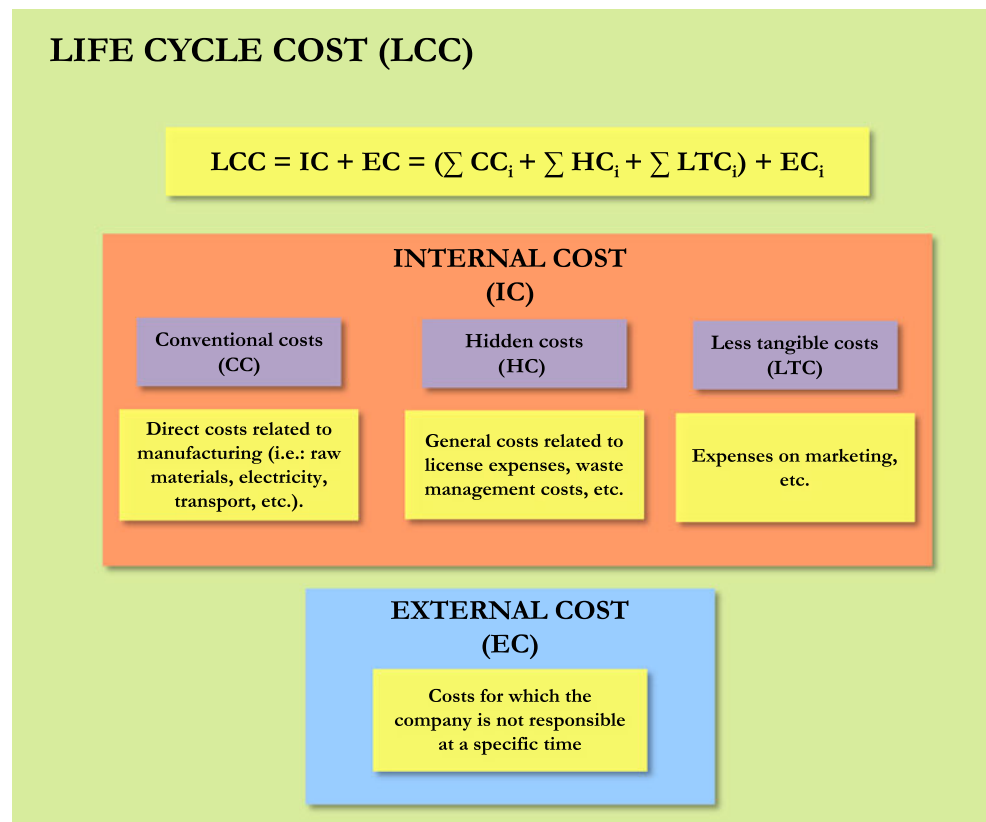


Figure 2 shows how Bovea and Vidal's sustainability methodology was applied to SustainPack research presented in this paper for a consumer unit with or without an FBBD communicative device stuck. Once LCA, LCC (IC + EC) and WTP results were achieved for each scenario, the next step was to assess if a specific scenario was more sustainable than each other in relative terms in accordance with the sustainable conditions established in the methodology. The case studies selected for the sustainability assessment were the same as considered in the previous paper dealing with the LCA of these packaging systems (Dobon et al. 2011). However, up to four different LCC scenarios were considered in order to assess the influence of the FBBD cost over the sustainability of the communicative packaging concept.

2 Methods

2.1 Life cycle costing

An LCC analysis was applied to the aforementioned consumer unit comprised by the tray, sealing film, pork chops and the FBBD (the latter as function of the scenario considered). On the contrary to LCA methodology, LCC has

not been standardized yet. However, the following phases of the LCC (similar to those described for LCA) were defined:

- Goal, scope and system boundaries of the LCC study
- Cost calculations
- Interpretation of results

2.1.1 Goal of the LCC study

The main objective of LCC study was to assess and compare costs associated to the life cycle of a consumer

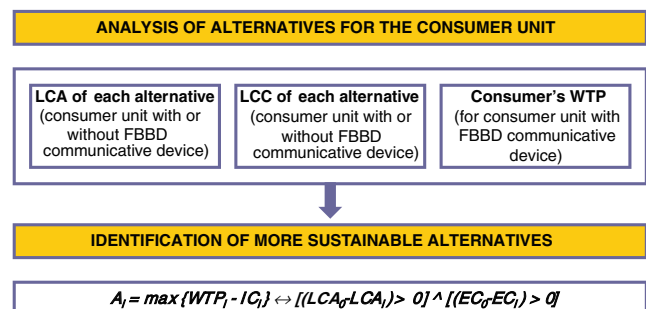


Fig. 2 Sustainability assessment of the case studies based on the Bovea and Vidal's methodology (Adapted from Bovea and Vidal 2004)

unit consisting of a nanoclay-based PLA package with or without an FBBD communicative device stuck and pork chops as contained product. Furthermore, some other secondary goals were achieved from LCC results:

1. To make a comparison between economic impacts related to consumer unit with or without FBBD communicative device.
2. To estimate the influence of FBBD communicative device in pork chop selling price at retail stores.
3. To estimate the economic savings of FBBD communicative device caused by the reduction of food losses at retail stores.

2.1.2 Scope of the LCC study

The same functional unit used in the previous LCA study (Dobon et al. 2011) was considered in this LCC: the production, packaging and delivery to the point of sale of 1,000 kg of pork chops in The Netherlands using nanoclay-based PLA packaging having affixed or not an FBBD communicative device. Therefore, the whole consumer unit (product plus package) was considered.

Likewise, the same scheme and reference flow used in the LCA for the life cycle of the consumer unit (Dobon et al. 2011) were considered in order to allow comparisons between LCC and LCA. As a result of that, four different life cycles were identified in order to carry out the LCC calculations: (1) pork chops life cycle (2) package life cycle, (3) FBBD communicative device life cycle and (4) life cycle for the logistic supply chain of consumer units. The life cycle scheme considered within the LCC study is shown in Fig. 3.

2.1.3 System boundaries

As shown in Fig. 3, the system boundaries included the raw material extraction, the packaging production and the meat processing, as well as the delivery to the retail outlet. As explained in the LCA (Dobon et al. 2011), use and end-of-life phases were excluded from the system boundaries. Furthermore, research and development costs related to fundamental and applied research (e.g. study of new packaging composition, development of new dispersion process for nanoparticles in polymer matrix, etc.) were not considered because expenditures for industrial research are often confidential and difficult to identify.

Besides the assumptions of the LCA (Dobon et al. 2011), some additional assumptions were considered in the implementation of the LCC for the consumer unit:

- Key assumptions on the pork chops life cycle. In the absence of detailed data about cost related to farming and growing of pigs and pig slaughtering phases, it

was assumed that pig carcass price¹ in The Netherlands represents the cost related to pig production and comprises all costs related to these phases of life cycle: energy consumption, labour cost, etc. In the remaining stages (meat processor: pork chops production + packing of pork chops), the most important economic inputs were considered: packaging cost, pork cost, energy cost, green taxes² (Nedvang 2007), labour cost and profits to meat processor.

- Key assumptions on the package life cycle. For raw material extraction phases, in the absence of detailed economic data, it was assumed that raw material purchasing cost comprises all costs³ related to its extraction and processing (energy consumption, machinery and facility repayment, salaries, indirect costs, etc.). For package manufacturing phases (nanoclay-based PLA and SiO_x-coated sealing film manufacturing), the most important economic inputs were analysed: raw material cost, energy cost, labour cost and profit, based on energy and material flows considered in the previous LCA (Dobon et al. 2011).

- Key assumptions on the life cycle for the logistic supply chain of consumer units. An estimation of global cost of the logistic supply chain of consumer units was made in accordance with existing economic studies in the pork supply chain (European Commission 2007). It was also assumed that the cost related to the life cycle of the logistic supply chain of consumer unit is comprised by several steps: energy consumption related to consumer unit storage and refrigeration, labour cost, maintenance expenses, etc. The same scenarios proposed in the LCA study were considered for the LCC (Dobon et al. 2011), although two new scenarios with FBBD were also added in order to take into account the influence of the price of an FBBD (Table 1). With regard to the food losses, the same percentages at retailer's outlet were considered (0.5 % for the scenarios with FBBD⁴ and 3.5% for the scenario without FBBD - scenario 2-). Such data were used to evaluate economic savings achieved by the use of the FBBD communicative device due to shrinkage reduction (Kreft et al. 2006), that is reduction of the amount of product waste.

¹ European market prices for pork have reference to cost market prices of slaughtered pig carcasses.

² According to Dutch new legislation on packaging waste (Nedvang 2007), companies that bring packaging to the market must pay a fixed fee for all packaging. Furthermore, business that place on the market 15,000 kg or more of consumer packaging and plastic drink packaging without deposit must pay a variable fee in addition to the fixed fee.

³ Transport costs from raw material manufacturer to packaging processor were not included in this cost since they were estimated separately.

⁴ Scenarios 1, 3, and 4.

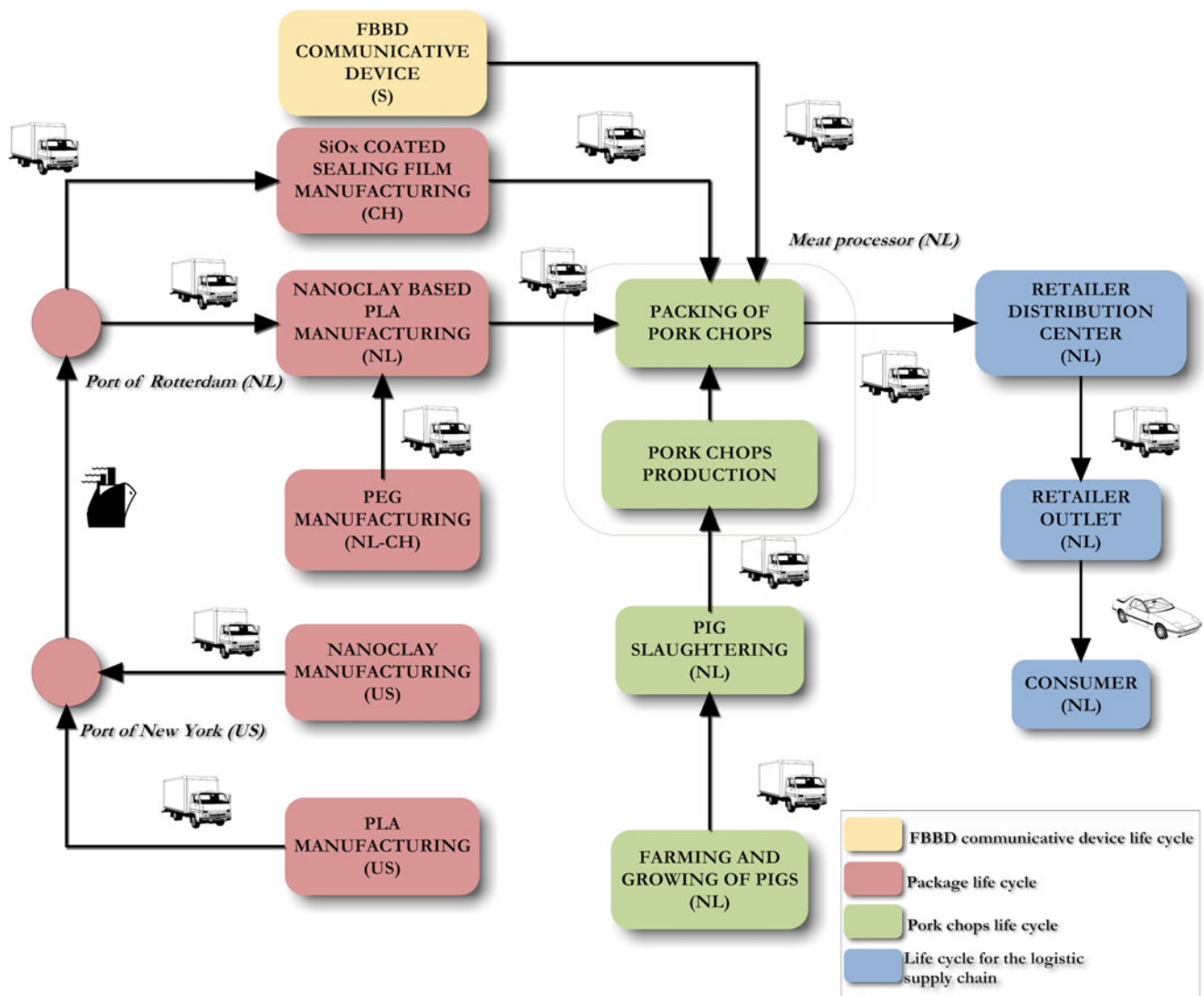


Fig. 3 Life cycle considered within this study (Dobon et al. 2011)

For that purpose, economic losses (EL) were calculated as follows (Kreft et al. 2006):

$$\text{EL(euros)} = \text{amount of shrinkage reduction (kilograms)} \\ \times \text{retail purchase price (euros per kilogram)}$$

where retail purchase price of the product was estimated as the sum of all internal costs related to the whole life cycle for the consumer unit.

▪ Key assumptions on the FBBID communicative device life cycle. It was assumed that the FBBID communicative device' purchasing cost comprised all costs related to previous stages such as raw material extraction and manufacturing. One of the main difficulties on the LCC of the FBBID was that any data were found in the literature since this type of communicative packaging device was at an early stage of development. For this reason, a cost estimation of the FBBID communicative

device was made. In accordance with authors like Robertsson (2008), it is expected that technological advances of these new communicative devices will generate further improvements in price competitiveness, and prices for large-scale volumes will be between 1–10 € cents/unit in the future. Therefore, four different scenarios were considered for the FBBID purchasing cost in order to consider such changes in cost (Table 1).

Table 1 Scenarios considered in the LCC study

Scenario	FBBID communicative device purchasing cost (€/device)
Scenario 1	0.05
Scenario 2	No FBBID device affixed
Scenario 3	0.01
Scenario 4	0.1

- Key assumptions on transport operations. In this LCC study, the same framework considered in the LCA was applied (Dobon et al. 2011). These costs were calculated with distances, diesel consumption, refrigeration, operation, etc.

2.1.4 Cost calculations

For cost calculations, the LCC methodology proposed by Bovea and Vidal (2004) was taken into account. According to Bovea and Vidal's LCC methodology, not only costs related to material and energy flows (IC) are considered but also costs due to impacts over the whole society that the system product under study may cause (EC). Therefore, in order to assess the IC, the most important economic inputs were analysed: raw material cost, energy cost, labour cost and profit; taking into account energy and material flows considered in the LCA (Dobon et al. 2011).

On the other hand, the EC related to costs of emissions⁵ and noise⁶ were analysed using economic parameter values as stated in Table 2. Even the methodology proposed by Bovea and Vidal also consider external costs due to congestion, these types of costs were not considered in the study since these remain controversial (Craighill and Powell 1996). This is sound since road congestion is highly dependent on the geographical scope as well as the route considered. A similar approach was considered for road casualties since these are a source of uncertainty, and economic parameters for that issue are highly dependent on the country.

The goal and scope for external costs calculations were the same as those used for internal costs calculations in order to ensure the consistency of such analysis. Furthermore, all energy and material flows considered in the LCA (Dobon et al. 2011) were taken into account for the assessment of the external costs since the components of the external costs are related to the effect of some chemical compounds produced during the whole life cycle of the consumer unit as well as the distances covered in the supply chain (Table 2).

2.1.5 Interpretation of LCC results

In accordance to the goals stated in Section 2.1.1, results were divided into three categories:

1. Comparisons between economic impacts related to consumer unit with or without FBBD communicative

device. These results are shown in Table 3. This table provides a comparison of internal, external and total life cycle cost results for each scenario considered in this study. Furthermore, internal cost breakdown (pork chops, packaging, FBBD communicative device, logistic supply chain of consumer units and transport) is also stated in Table 3. Different conclusions can be drawn from these results. On the one hand, internal costs (IC) represent more than 99% of the total life cycle cost for all scenarios considered; consequently, the external cost (EC) result was negligible compared with the internal costs (IC) in all scenarios, since these represent less than 1% of the total life cycle cost (caused mainly by NO_x, CO₂ and particulate emissions due to transport operations). On the other hand, internal costs related to pork chops and logistic supply chain of consumer units are more relevant than internal costs related to packaging, FBBD communicative device and transports, since they represent more than 90% of global internal cost for all the scenarios considered. A deep analysis on the internal costs reveals that in the scenario 2 (no FBBD stuck to the package), the total internal cost is higher than in the scenarios 1 and 3. This is due to the fact that the percentage of food losses is higher than in the case when an FBBD is used. Consequently, a higher amount of consumer units is required to fulfil the functional unit selected: 2,941 consumer units when FBBD is used and 3,029 when FBBD is not used. Therefore, more pork chops, packaging or cost related to supply chain of consumer units are required. However, in scenario 2 (base case where the FBBD is not used), the transports costs are less than in the remaining scenarios, since the transport of the FBBD communicative device is not included in the calculations, although a higher amount of consumer units is required to fulfil the functional unit. Moreover, external costs are higher in the case of the packaging system without FBBD device (scenario 2). This is due to the minimization of product waste (shrinkage) derived from the use of the FBBD that reduces the amount of food and packaging that becomes waste at retailer.

2. Influence of FBBD communicative device in pork chop selling price at retail stores. The sum of all internal costs expressed as euros per consumer unit inputs allows getting an estimated total cost price for the product at the retail stores. Figure 4 shows the influence of FBBD cost in selling price. In Fig. 4, it is observed that the selling price of consumer units of pork chops increases if the packaging system includes an FBBD. Pork chop selling price increases between 0.1 and 0.01 € when the communicative device is used since the purchasing cost of this communicative device is included in the price. That means an increase of

⁵ For EC calculation arising from emissions, only several well-known substances were accounted (CO₂, CO, CH₄, SO₂, NO_x, N₂O and particulates).

⁶ The external cost related to noise was calculated through the accounting of the equivalent distance covered by each consumer unit during all transport operations.

Table 2 Economic parameter values for external costs (EC)

Emission (Craighill and Powell 1996) (€/kg)		Road congestion (Craighill and Powell 1996) (€/km)		Road casualties(Craighill and Powell 1996) (£/casualty)		Noise (Quinet 1996) (€/100 t km)	
CO ₂	0.006	Motorway	0.004	Mortality	744,060	Train	0.12-0.13
CO	0.009	Non-central	0.189	Serious injury	84,260	Road	0.11-0.19
CH ₄	0.111	Rural	0.001	Minor injury	6,450	Plane	2.3
SO ₂	3.972						
NO _x	1.952						
N ₂ O	0.944						
Particulate	13.804						

Adapted from Bovea and Vidal (2004) and Craighill and Powell (1996)

2.27% of pork chop selling price for consumers in scenario 1, 0.45% in scenario 3 and 4.54% in scenario 4.

3. Influence of the FBBD communicative device upon economic savings due to the reduction of food losses at retail stores. As stated above, it was considered that the shrinkage of the meat product might reduce from 3.5% to 0.5% at retailer (van der Heijden et al. 2007) as a result of the use of an FBBD. Consequently, it was expected to achieve economic savings due to the reduction of food losses at retailer outlets. The economic savings were based on the formula stated above in Section 2.1.3 and suggested by Kreft in the framework of SustainPack project (Kreft et al. 2006), where the shrinkage reduction is the reduction of the amount of product waste:

$$EL_i(\text{euros}) = \text{amount of shrinkage reduction (kilograms)} \\ \times \text{retail purchase price (euros per kilogram)}$$

Comparisons among each scenario were made by fixing the scenario 2 (consumer unit without FBBD) as base case.

Therefore, economic savings (ES) at retailer's outlets for each scenario were estimated as follows:

$$ES_i(\text{euros per consumer unit}) = EL_0 - EL_i$$

where:

ES_i Economic savings for the scenario considered

EL₀ Economic losses for the scenario base (scenario 2)

EL_i Economic losses for the scenario considered

Table 4 summarizes the economic losses and economic savings due to the reduction of food losses for all four scenarios. Some differences about economic losses between each scenario can be drawn from Table 4. In scenarios 1, 3 and 4, economic losses are lower than in scenario 2 due to the minimization of the amount of food losses, even though there was an increase of the total cost due to the FBBD use. Therefore, a maximum price of 0.02€/FBBD is required to compensate the economic savings due to food losses.

Table 3 LCC results (expressed as euros per functional unit)

	Scenario 1 (with FBBD 0.05€)	Scenario 2 (without FBBD)	Scenario 3 (with FBBD 0.01€)	Scenario 4 (with FBBD 0.1€)
Pork chops life cycle	4,223.556	4,349.933	4,223.556	4,223.556
Life cycle of the logistic supply chain of consumer units	1,906.177	1,963.214	1,906.177	1,906.177
Package life cycle	266.688	274.668	266.688	266.688
FBBD life cycle	147.050	0.000	29.410	294.100
Transports	64.959	63.594	64.959	64.959
Internal cost (IC)	6,608.431	6,651.408	6,490.791	6,755.481
Emissions	24.668	25.163	24.668	24.668
Noise	1.159	1.159	1.159	1.159
External cost (EC)	25.827	26.321	25.827	25.827
Life cycle cost (LCC)	6,634.257	6,677.322	6,516.617	6,781.307

2.2 Social assessment: willingness to pay

As stated in Section 1, LCA and LCC analyses must be complemented with a consumer acceptance study in order to know how much the consumer is willing to pay for the FBBD as well as allow subsequent sustainability assessment of alternatives. Therefore, an assessment of the willingness to pay (WTP) based on the contingent valuation technique (CV) was carried out in the SustainPack project.

The WTP evaluation was carried out in two stages. The first stage was developed by set focus groups with consumers. Such focus groups were held in Denmark, Slovakia, The Netherlands and Spain. In these focus groups, consumers were asked about their perceptions, potential use of communicative packaging developments, etc. and also about the WTP for these devices. A wide range of consumers participated in the focus groups. The strata included male and female consumers between 20 and 69 years who are responsible for buying groceries on a regular basis. Fifty-one people participated in the focus groups. From them, 2/3 were female and 1/3 were male (Antvorskov 2007).

In a second stage, retailers were interviewed about their perceptions on the FBBD and asked for an estimation of the WTP of consumers for such device. The interviews with retailers took place with supermarket managers with high experience in product pricing and therefore had a good feeling on how much a consumer is willing to pay for communicative packages. Such interviews were performed in Denmark, The Netherlands and Spain. Thirteen retailers were interviewed, most of them related to food retail sector, covering a considerable share of the market in each of these countries. As a result of the social assessment, a maximum WTP value of 0.1€/FBBD was obtained from the focus

groups with consumers. On the other hand, an average WTP value of 0.05€/FBBD was stated by the retailers. Additionally, results coming from the consumers were cross-checked with the data provided by the retailers in order to obtain an accurate measure for the WTP of an FBBD. The final value of WTP for such a device was estimated to be 0.05€/FBBD device.

2.3 Sustainability assessment

As stated above, the sustainability assessment approach proposed by Bovea and Vidal (2004) was considered in this research in order to obtain a sustainability measurement for each scenario considered in this study, based on the three-pillar approach (environment, economy and society; Fig. 5):

- Environment: Through the environmental impact evaluation carried out by an LCA of the case study for the selected consumer unit with and without FBBD communicative device (Dobon et al. 2011).
- Economy: By the LCC analysis of the selected consumer unit and FBBD device (Section 2.1)
- Society: Using a customer valuation (both retailers and consumers) by asking them about the WTP of the new communicative packaging development (Section 2.2).

Therefore, when the LCA results, LCC (IC + EC) results and WTP were achieved, the next step was to assess if a specific scenario is more sustainable than each other in relative terms. Consequently, a base case was fixed in order to allow relative comparisons. The scenario 2 (consumer unit without FBBD affixed) was selected as base case. Then, the sustainable alternatives were assessed by fulfilment of the following equation:

$$A_i = \max\{WTP_i - IC_i\} \leftrightarrow [(LCA_0 - LCA_i) > 0] \\ \wedge [(EC_0 - EC_i) > 0]$$

Where:

LCA_0	Environmental LCA result (per impact category) of the base case
LCA_i	Environmental LCA result (per impact category) of the alternatives
EC_0	External cost of the base case
EC_i	External cost of the alternative
WTP_i	Willingness to pay of the alternative
IC_i	Internal cost of the alternative
$(LCA_0 - LCA_i)$	Environmental term (condition 1)
$(EC_0 - EC_i)$	Cost term (condition 2)
$(WTP_i - IC_i)$	Social term (condition 3)

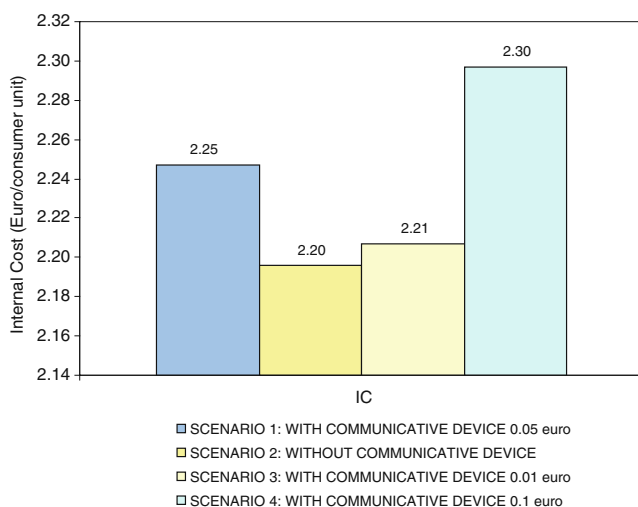


Fig. 4 Influence of FBBD communicative device cost over pork chop selling price

Table 4 Comparison of the economic losses and savings due to food losses among the scenarios considered within the study

	Scenario 1	Scenario 2 (base case)	Scenario 3	Scenario 4
A: FBBD purchasing cost (€/device)	0.05	N/A	0.01	0.1
B: Total weight per consumer unit (kg/consumer unit)	0.355	0.354	0.355	0.355
C: Percentage of food losses (% wt) ^a	0.5	3.5	0.5	0.5
D: Estimated consumer unit selling price (€/consumer unit)	2.25	2.20	2.21	2.3
E: Amount of shrinkage reduction ^b (kg/consumer unit)= $B \times (C/100)$	0.0018	0.0124	0.0018	0.0018
F: Economic losses due to food product losses (€/consumer unit)= $D \times E$	0.0040	0.0273	0.0039	0.0041
G: Economic savings due to the reduction of food losses referred to the base case (€/consumer unit)	0.0233	0.0000	0.0233	0.0232

^a Please also note that this percentage includes both the meat and the packaging

^b Reduction of the amount of product waste

In accordance with the equation, the most sustainable alternatives will be achieved when the environmental and cost terms are positive and the difference in social term reaches its maximum value.

3 Results and discussion

Results on the sustainability assessment are shown in Tables 5 and 6. Table 5 summarizes the results of the condition 1 (environmental term), whereas Table 6 shows the results for condition 2 (cost term) and condition 3 (social term). The main result that can be drawn from these tables is that the most sustainable alternative is the one in which the FBBD cost is 0.01€/unit (scenario 3) since the maximum value for the social term ($WTP_i - IC_i$) is obtained as well as the environmental term ($LCA_0 - LCA_i$) and cost term ($EC_0 - EC_i$) remain positive.

The second alternative in terms of sustainability is the case in which the FBBD cost reaches up to 0.05€/unit (scenario 1). In that case, the environmental term and the

cost term are positive, but the value for ($WTP_i - IC_i$) term is lower than in scenario 3.

The third alternative is the case in which the FBBD cost is 0.1€/unit (scenario 4). This alternative is not sustainable anymore since a negative value is obtained for the ($WTP_i - IC_i$) term despite of the fact that the environmental and cost term remain also positive.

In accordance with the sustainability assessment results, prices for the FBBD should be lower than 0.05€/unit in order to be sustainable. In case that the FBBD purchasing cost is higher than 0.05€/device, a negative result is obtained for the social term, meaning that the FBBD price must be more competitive in order to be accepted by consumers.

After using Bovea and Vidal's methodology for evaluation of sustainable alternatives, several strengths and weaknesses were also identified. The main strength of the method is that it allows performing quantitative sustainability assessments as well as the integration of other well-known methodologies for environmental, economic and social assessments. However, the main weakness of the method was found on the huge amount of data required before performing the sustainability assessment. Also, previous LCA, LCC and CV of the WTP are required before the sustainability assessment. This is time-consuming and makes its implementation difficult at company level. Another important weakness is the calculation of external costs since this could introduce uncertainty in the results.

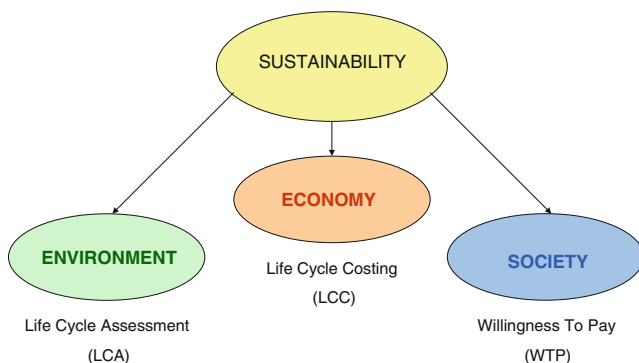


Fig. 5 Data sources for sustainability assessment based in the triple bottom line approach (source: own elaboration)

4 Conclusions

Several conclusions can be drawn from the work carried out in the LCC/CV/sustainability assessment presented in this paper. With regard to the LCC, it is clearly observed that

Table 5 Sustainability assessment for Condition 1 (environmental term)

		Scenario 1	Scenario 2 (Base case)	Scenario 3	Scenario 4
Use of FBBD device		Yes	No	Yes	Yes
Estimated FBBD cost (€/device)		0.05	0	0.01	0.1
Condition 1: Environmental term	Carcinogens (DALY)	1.00E-11	N/A	1.00E-11	1.00E-11
LCA ₀ -LCA _i (Unit / consumer unit)	Resp. organics (DALY)	1.20E-11		1.20E-11	1.20E-11
	Resp. inorganics (DALY)	1.10E-08		1.10E-08	1.10E-08
	Climate change (DALY)	7.00E-09		7.00E-09	7.00E-09
	Radiation (DALY)	4.00E-13		4.00E-13	4.00E-13
	Ozone layer (DALY)	4.00E-12		4.00E-12	4.00E-12
	Ecotoxicity (PAF*m2yr)	1.00E-05		1.00E-05	1.00E-05
	Acidification/Eutrophication (PDF*m2yr)	3.00E-03		3.00E-03	3.00E-03
	Land use (PDF*m2yr)	4.00E-02		4.00E-02	4.00E-02
	Minerals (MJ surplus)	1.60E-05		1.60E-05	1.60E-05

when the FBBD is used, the internal costs are generally lower than in those cases where the FBBD is not. This is due to the minimization of food losses from 3.5% (packages without FBBD) to 0.5% (packages with FBBD). Furthermore, the internal costs are clearly higher than the external costs. In spite of these differences on the scale, external cost results show the economic advantages of FBBD for packaged perishable products since it contributes to the increase in economic savings due to the reduction of food losses. However, these economic savings represent only a small percentage over consumer unit selling price. As a result of that, the economic savings due to food losses are only covered when the cost of the FBBD is less than 0.02€/device. Furthermore, the analysis of WTP performed with consumers and retailers revealed a maximum cost for the FBBD device of 0.05€. The combination of LCA, LCC and CV of WTP together with the conditions of the equation for sustainability evaluation of alternatives showed that the most critical condition was the social term (WTP vs IC). Consequently, the maximum difference between the WTP and the internal costs of consumer units is a key point to

provide sustainable alternatives whenever economic and environmental conditions remain positive. Therefore, as less as possible price satisfying the WTP of consumers results in more sustainable packaging. Furthermore, the use of Bovea and Vidal's methodology resulted in quantitative assessment of alternatives based on well-known assessment methodologies (LCA, LCC and CV). However, a huge amount of data was required, and the evaluation of external cost could introduce uncertainty in the results.

5 Recommendations

One of the main barriers for the competitiveness of FBBD is the absence of economies of scale, utilization of plant capacity and improvement of technology. Nevertheless, it is expected that prices for large-scale volumes will be between 1 and 10€ cents/unit (Robertsson 2008), and the estimated WTP by consumers is 5€ cents/device (Kreft et al. 2005). Therefore, as less as possible price satisfying the WTP of consumers results in more sustainable packaging. It

Table 6 Sustainability assessment for conditions 2 (cost term) and 3 (social term)

			Condition 2: cost term	Condition 3: social term
	Use of FBBD device (yes/no)	Estimated FBBD cost (€/device)	EC ₀ - EC _i (€/consumer unit)	WTP _i - IC _i (€/consumer unit)
Scenario 1	Yes	0.05	1.68E-04	0.00
Scenario 2 (base case)	No	0	N/A	N/A
Scenario 3	Yes	0.01	1.68E-04	0.04
Scenario 4	Yes	0.1	1.68E-04	-0.05

is expected that this situation will change in the future since further improvements on FBBD will result in more price competitiveness.

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